Memorandum:

Sediment Concerns in Headwater Streams on State and Private Forests in the Pacific Northwest: A Brief Review of Directly Pertinent Science

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Abstract

Recent studies help elucidate the potential importance of Pacific Northwest logging practices on "dispersed" erosion and sediment delivery to headwater streams, apart from the more widely recognized point sources of roads and landslides. Rashin et al. (20 06) show that near-term and immediate effects of logging on direct soil disturbance are substantial and pervasive, but can largely be avoided through no-yarding, no-felling, no-cut buffers strips extending a minimum 30 m from the stream margin, extended wider to encompass steep inner gorge slopes where present.

Reid et al. (2010), Klein et al. (2012), and Keppeler (2012) taken together show that even when buffer strips are left, logging of upland slopes results in increased runoff, which in turn can cause channel and gully erosion, stream network expansion into previously unchanneled headwater swales, and persistently elevated suspended sediment. Expanded channel networks post-logging generate new sediment, and also infiltrate sediment sources that were previously unconnected to surface waters. These changes and related geomorphic adjustments may cause recurring episodes of turbidity many years after logging. Turbidity impacts generally propagate to downstream receiving waters. This impact can be partially but not fully mitigated by riparian buffers. Where stream and wetland densities are not high, it could potentially be fully mitigated only by limiting logging rate and pattern within and among small catchments to minimize the marginal hydrologic effects of logging in the face of natural vegetation disturbances.

Introduction

Headwater streams by definition contribute water and sediment to downstream areas, hence are critical in determining water quality and habitat conditions for aquatic resources in receiving waters across the landscape (Likens and Borman 1974, Lowe and Likens 2005). But headwater streams themselves are by linear extent the most abundant freshwater habitat in Pacific Northwest landscapes, and themselves constitute important water resources and habitats for many animal and plant species. Olson et al. (2007) reviewed the importance of sediment and erosion and deposition processes in affecting stream-associated amphibians and determining sedimentation, water quality, and habitat features in downstream, fish-bearing waters. While the effects of logging, including increased sediment delivery to headwater streams can be at least partly mitigated by riparian buffers (within which logging operations, including ground disturbance and tree removal, are excluded), some larger-scale effects of logging across catchments tend to be pervasive, and not fully mitigated by narrow forest buffers. Moreover, most non-fish-bearing headwater streams, especially those that lack permanent or continuous flow, are not required to be buffered under current state rules governing private forest practices in private lands (Olson et al. 2007).

Headwater streams lie at the erosional interface of the stream network and hillslopes. Not only are steep headwater streams the recipients of erosion and sediment generated by hillslope processes, they are themselves formed and maintained by erosional and sediment transport processes. Changes in the dynamics of erosion and sediment delivery, then are dramatically and rapidly expressed as changes in channel stability, morphology, and turbidity in headwater streams. Gomi et. al. 2005 reviewed the variety of processes and conditions that initiate and mediate the consequences of suspended and fine sediment in headwater streams in the Pacific Northwest. While the roles of forest roads and by landslides in delivering sediment to streams have received much scientific and some policy attention in recent decades in the Pacific Northwest, we have long known that forest practices also introduce sediment to streams via direct ground disturbance, and by way of alteration of catchment-wide hydrology following vegetation removal. Recent scientific information points to a need to re-examine current forest practices in light increasing understanding of these "dispersed" erosion and sediment sources.

In this short memorandum I focus on three relatively recently-published journal articles that provide important new information on sediment sources, sediment delivery, fine sediment effects, and the effectiveness of stream buffers in mitigating sediment delivery associated with logging practices in forested watersheds of the Pacific Northwest. These studies are directly relevant to key questions that receive insufficient attention in policy debates: the need for buffers on headwater streams, critical design considerations for such buffers, and the need to regulate harvest rates within and across catchments.

1) Rashin, E. B., C.J. Clishe, A.T. Loch, and J.M. Bell. 2006. Effectiveness of Timber Harvest Practices for Controlling Sediment. Journal of the American Water Resources Association 42:1307-1347.

Based on systematic field surveys of ground and channel conditions, Rashin et al. (2006) examined immediate effects of logging-related ground disturbance on slope erosion, sediment routing, and headwater stream channel condition in forested industrial forestlands of Washington. The slope erosion study employed a between-sites-comparison design with unlogged sites as controls, and stream channel condition surveys used a before-and-after-logging design. Results were presented as a direct examination of near-term BMP effectiveness under forest practices rules that at the time allowed a variety of logging actions along non-fish-bearing, headwater streams, but did not require continuous riparian forest buffers.

This study found that riparian vegetative buffers (*ca.* 10m or more wide on each side of channel), including leave tree areas and with required directional felling and restrictions on log yarding or ground-based equipment use, were wholly or partially effective in preventing near-term sediment delivery from logging disturbance. Area of exposed soil that delivered sediment to stream channels was an order of magnitude higher in sites logged without stream buffers compared to those logged with buffer.

Effectiveness of stream buffers was breached at yarding corridors through buffers (associated with ground scars from cable yarding), and where selective logging occurred on steep inner gorge slopes within (or possibly adjacent to) the buffer areas. Stream buffers were generally effective at reducing near-term sediment delivery to streams regardless of whether surrounding logging was by clearcut or partial cut. However, yarding corridors measurably compromised the effectivenes of stream buffers in preventing sediment delivery.

Stream buffers were most effective where timber felling and yarding activies were kept at least 10m from streams and kept outside of steep inner gorge slopes. Simple exclusion of logging-caused ground disturbance from near-stream areas and hillslopes with a light likelihood of delivery of sediment to channels accounted for most of the effectiveness of stream buffers.

The primary observed causes of soil disturbance and erosion were skid trails from tractor yarding and yarding scars from cable yarding. Relict but ongoing erosion sources associated with roads, skid trails, and landslide scarps that had existed prior to the latest logging were also observed, but with lower frequency.

Windthrow of leave trees in stream buffers was frequent, but a far less important contributor of sediment than yarding scars and other ground disturbance, because the localized, self-draining topography of root throw pits discouraged sediment routing to nearby streams. This contrasted with the linear, down-slope oriented, and often larger features caused by direct logging disturbance. Windthrow of trees growing on the immediate streambank was seen to contribute sediment to streams, but this apparently was not the predominant location of blowdown. Surrounding logging prescriptions was seen to affect the windfirmness of stream buffers. Incidence of windthrow within buffers adjacent to clear cuts was an order of magnitude higher than within buffers adjacent to partial cuts, and also greater than riparian area windthrow within unlogged control watersheds. Recently, Schuett-Haes et al. (2012) reported the results of a study of windthrow in buffers along non-fish-bearing, perenial streams in western Washington. While they found a high incidence of windthrow within the first five years after logging, similar to Rashin et al. they observed relatively limited sediment delivery to streams from windthrown trees within stream buffers.

Rashin et al. reported that where riparian vegetative buffers were not left, erosion and channel response were clearly linked to surrounding logging practices. Namely, clearcuts tended to exhibit more sustained active erosion and sediment delivery than partial cuts. In winter-cold, interior forests, logging over snow and frozen ground appeared to substantially reduce observed erosion and sediment delivery.

Despite that most streams in the study were small headwater channels with steep channel slopes (exceeding six percent), surveys revealed numerous instances of fine sediment accumulation on streambeds, both in pools and across the entire bed, associated with localized sediment sources (and in some cases, accumulations of logging slash). In addition, the extent of actively eroding streambanks increased in streams logged without buffers. These observations contradict the oft-repeated but seldom-tested presumption that sediment entering steep headwater streams is "rapidly flushed out" and therefore has presumably little effect in instream biota and water quality. Gomi et al. (2005) have previously commented that sediment routing and fate in headwaters streams in the Pacific Northwest has received insufficient study relative to the risks fine sediment poses to aquatic resources.

Note the Rashin et al. study is conservative in the sense that "controls" were previously-logged, second-growth sites, and hence "background" or baseline incidence of erosion was likely elevated over natural rates in watersheds not previously disturbed by logging and roads (see below, Keppeler 2012).

Nevertheless the analysis provides a useful basis for evaluating future management of the existing, largely second- or third-growth, road-private forest landscape.

The most important caveat is that this study only evaluated localized erosion and sedimentation within the immediate two years after logging. Many potential sources of impact to streams, including those that result from hydrologic change caused by vegetation removal, and those that propagate over time and space, were not accounted for in the study design. Hence it is also important to recognize that these might not be fully mitigated by riparian buffers. Such processes include headward channel incision or gullying, landslides that increase with root strength depression occurring several years after harvest, and streamside erosion increases resulting from debris flow scour or the passage of coarse sediment waves.

2) Reid, L.M., N.J. Dewey, T.E.; Lisle, and S. Hilton. 2010. The incidence and role of gullies after logging in a coastal redwood forest. ***Geomorphology*** **117: 155-169. http://naldc.nal.usda.gov/download/40745/PDF**

Although expansion of headwater channels has been an often-suggested cause of post-logging erosion, this key paper is apparently the first comprehensive and systematic study to assess the quantitative extent and sediment source contributions of this phenomenon. In Caspar Creek, north coastal California, this study found that second-growth logging of a redwood-dominated forest was followed by a substantial headwater expansion of stream channels density and coalescence of pre-existing discontinuous channels in headwater swales.

Despite "robust" riparian buffer strips left in the second round Caspar Creek logging during this study, suspended sediment yields increased in instrumented tributaries significantly after logging. Channel expansion was caused by observed headward migration of existing channel knickpoints and subsequent channel incision and enlargement, as well as sapping and collapse of subsurface flow macropores and pipes. Acceleration of surface and subsurface channel-forming processes was apparently associated with increased antecedent moisture conditions, soil saturation, and runoff caused by the abrupt reduction of forest canopy interception and evapotranspiration following logging. In addition, back erosion of extant channels increased in linear extent, possibly reflecting increased channel-forming flows possibly coupled with impingement of hillslopes that could have been creeping at faster rates in the years immediately following logging (e.g., see Swanston et al. 1988).

Channel heads after logging were located substantially upslope from their pre-logging conditions. Observed channel incision through the extensive root frameworks of aboriginal redwood stumps and through weathered bedrock layers (saprolite) suggest that the present channel network has expanded well historical pre-logging conditions in Caspar Creek. Time–trend monitoring and reconstruction indicate stream density increased by about 28 percent after the most recent round of logging.

Expanded channel networks are associated with persistent increases in peak flow magnitude, which may result from more rapid translation of slower subsurface to rapid surface flow during storms. Erosion, both primary and secondarily associated with expanding or expanded channel networks, may be responsible for sustained elevation of suspended sediment yield and turbidity in Caspar Creek (reported in this study, Keppeler 2012, Klein et al. 2012, and discussed as a regional concern in the review by Gomi et al. 2005). Expanded channel networks increase surface water connectivity to and sediment delivery from pre-existing erosion sources like landslide scarps and roads, and can itself initiate additional mass erosion through bank collapse and trigging of channel-adjacent landslides.

If headwater streams are to be effectively protected against logging-related erosion, buffer design must anticipate headwater channel expansion, with a soil disturbance exclusion zones and vegetative buffers left in swales well above pre-logging channel head locations. However this does not prevent channel expansion; it only moderates its potential erosional impact. Fully controlling channel expansion effects on streamflow, erosion, and sedimentation would require limiting the overall rate of logging within small catchments over time, moderating silvicultural treatments to promote more rapid hydrologic recovery (e.g., via partial cutting rather than clearcutting), and careful consideration of past and future natural events, including wildfire, windthrow, and disease which, independent of or interactively with logging, also alter the hydrologic effects of vegetation. In other words, substantial changes of silvicultural methods and reduction of overall rates of vegetation disturbance would likely be necessary for logged watersheds to remain within unimpaired, natural erosional and water quality limits.

In Caspar Creek, overall erosion in upland areas, including diversion-induced mass wasting, incision of crossings along untreated roads and skid trails, and in-channel gullying of headwater streams and zero-order basins, remains active. These sources have caused a sustained, second peak in suspended sediment yield about 20 years after initial logging (the first peak and temporary “recovery” occurred within the initial decade after logging) (Keppeler 2012).

3) Klein, R.D., Lewis, J., Buffleben, M.S. Logging and turbidity in the coastal watersheds of northern California. Geomorphology, Volumes 139–140, 15 February 2012, Pages 136-144, ISSN 0169-555X, 10.1016/j.geomorph.2011.10.011. Downloadable from: http://www.sciencedirect.com/science/article/pii/S0169555X110052 77

Examining continuous turbidity records from 26 coastal watersheds in northern California, Klein et al. found that the extent (or rate) of recent logging activity (mean annual percent of watershed area logged within the last decade) was the strongest predictor of the duration of chronic turbidity. Road indices, and a large set of physiographic watershed characteristics were not correlated with chronic turbidity, except for a weak positive association with drainage area.

The study implicates the importance of headwater sources associated with ground disturbance and catchment-scale hydrologic change that can lead to channel expansion and gullying, as well as landslides; the authors conclude that "Despite much improved best management practices, contemporary timber harvest can trigger serious cumulative watershed effects when too much of a watershed is harvested over too short a time period."

Discussion

To my knowledge, the concerns raised in the Caspar Creek research (and previously identified as important in other areas, such as the Idaho Panhandle National Forest) have not previously been considered in Oregon Forest Practices discussions. This is an important scientific oversight. I have personally observed abundant evidence for the processes Reid et al. describe from Caspar Creek in my own research in the Oregon Coast Range and Klamath Mountains. (E.g., my Master's research at OSU was focused on exactly these kinds of headwater stream conditions in logged and unlogged watersheds of the Coast Range west of Corvallis, and what I observed is entirely consistent with Reid's description and inferences.) By contrast, the relatively immediate and direct erosion impacts observed by Rashin et al. (2006) are more widely recognized, but their consequences are commonly overlooked or minimized by pointing to the evidently larger sediment impacts associated with road and landslide sources. Currently in many areas of moderate or high road density, road-related impacts on streams likely are of such magnitude as to indeed obscure dispersed erosion and catchment-scale hydrologic effects. However, if road restoration and remediation becomes more widely applied, with road systems rationalized and road densities reduced, the pervasive effects of other disturbances associated with logging and forest management will almost certainly become more evident.

It's worth noting that the Oregon Department of Forestry's summary report, "The Oregon Forest Practices Act Water Protection Rules: Science and Policy Considerations" (Lorensen et al. 1994, p. 14) states, without attribution or citation, that “Streamside buffers have been found to be relatively unimportant in preventing or reducing sediment delivery to streams.” When Oregon’s 1994 Forest Practices rules were finally adopted lacking continuous buffers on the vast majority of non-fish-bearing streams, it had been widely assumed, and was an oft-repeated meeting mantra, that "overland flow is relatively uncommon in the Pacific Northwest on forest soils,” and that somehow as a consequence of this, erosion simply was not an issue, except perhaps where roads intersected with streams (buffer design criteria then focused on shade and woody debris recruitment to stream channels). This construct appears to be rooted in an early, agronomy-dominated perspective view that soil erosion occurs only as a function of classically defined overland flow (plus rainsplash detachment of exposed soil particles). However, geomorphologists and forest soils scientists have long recognized that erosion in steep, forested landscapes is dominated by a host of processes other than overland flow. For example, the erosion and sediment delivery observed in Rashin et al. (2006) and Reid et al. (2012) was initiated or propagated by piping, sapping, channel incision and gullying by headcut migration, mass erosion, accelerated creep or solifluction, root throw, and direct physical disturbance and displacement of soils, debris, and stream channels by equipment or logging debris. Considering this list of processes, all have either been shown to be altered by logging activity, have been identified as having that potential, or are defined as being directly the product of it.

Roads may be highly correlated with watershed condition, but it is important to recognize that such a correlation does not necessarily mean that “fixing” roads will alleviate all of the correlated effects. Road density integrates at least two major and separate categories of phenomena that contribute to erosion and sediment delivery (Trombulak and Frissell 2000). The first is erosion and sediment that is generated by the road itself and operations on it, and runs off into surface waters. In this category we can include secondary hydrophysical effects of roads, including landsides and gullies that initiate because roads disturbed natural drainage pattern, and maintenance-related runoff. The second category is indirect: the erosion and sedimentation that are generated by land use actions and practices that are either supported by or incidental to the road network. Those phenomena in the second category that pertain to dispersed erosion and sediment delivery in forested watersheds are the subject of this memo: primarily, they are direct ground disturbance from felling and yarding, accelerated windthrow around cutting unit margins, and channel extension, gullying, and bank erosion initiating as a consequence of catchment-wide vegetation removal.

On private industrial forest lands there is commonly a very high correlation between between known road density and the spatial extent of vegetation disturbance (primarily by logging, but also herbicides, grazing, and fire) among watersheds, but that correlation gets weaker in some Coast Range watersheds that were in the past cut over in a short period of years, are now in an advanced second growth state and have seen relatively little thinning, alder conversion, “sanitation” cutting, or other logging disturbance in recent decades. Erosion may not be completely mitigated by reducing hydrologic connectivity of the road network, nor necessarily by directly by reducing road density through decommissioning , because dispersed erosion could continue if logging practices continue. However, road remediation and forest management planning that produce a major and lasting reduction in road density might secondarily limit the pattern and frequency of future logging and other vegetation management activity in ways that also limit hydrologic alteration and its resultant dispersed erosion.

Olson et al. (2007) suggested the possibility of adopting “islands,” large forest patches that include stream networks, as reserve areas that are not exposed to the effects of logging that occurs elsewhere on the landscape. Such reserves would encompass whole headwater catchments, but also lap across ridgelines to provide terrestrial microhabitat connectivity to adjacent watersheds. While consolidating and protecting some measure of biological habitat integrity locally, this approach alone would not comprehensively protect headwater streams, or downstream receiving waters, from the harmful effects of erosion and sediment delivery. To meet such broader goals or requirements , an “island” strategy would have to be coupled with comprehensive buffer protection for headwater stream networks (including perennial, ephemeral, intermittent, incipient channels in swales or zero-order basins, as well as forested wetlands).

Where stream density is very high (including some highly dissected coastal terrain and interior wetland-rich areas), including a larger total area of each headwater catchment within an extensive network of unlogged riparian buffers along headwater streams, un-channeled swales and wetlands would by default result in a restricted pattern of logging. This reduced footprint could substantially limit the extent of hydrologic alteration from logging at the catchment scale, thereby greatly diminishing the magnitude and spatial extent of gully erosion and channel expansion as sediment sources. In landscapes with lower stream and wetland density, catchment-wide processes would be more prone to push erosion processes even when expansive headwater riparian buffers were left. Where stream and wetland densities are not high, this impact could potentially be fully mitigated only by limiting logging rate and pattern within and among small catchments to minimize the marginal hydrologic effects of logging in the face of natural vegetation disturbances.

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